

Review of current research on native forest establishment on extremely eroded land

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Executive summary

Aotearoa New Zealand has a high proportion of steep, highly erodible land which could benefit from the establishment of forest. Highly erodible land is that classified as high (orange) or very high (red) under the Erosion Susceptibility Classification system, and 7e or 8e under the Land Use Capability classification system. Recent and historical cyclones and large storm events have significantly contributed to erosion, particularly landslide erosion in steep areas with a lack of vegetative cover such as marginal hill country in pasture. Besides providing a method of erosion control, establishing native forest can improve biodiversity and offer cultural and recreational benefits. However, establishing native plants on steep land poses a number of challenges including access, health and safety, and unsuitable environmental and soil conditions. A significant proportion of Māori land is classed as steep and erodible, and it is important to consider mana motuhake (authority and self-determination), whakapapa connections, kaitiaki responsibilities and mātauranga held by local iwi-hapū groups when implementing planting projects for erosion control.

A variety of techniques are being used to establish trees on erodible land both in New Zealand and internationally. This literature review explores the available information on techniques used for recent native tree establishment projects within New Zealand, as well as a review of techniques used internationally for erosion control, including bioengineering. The use of nurse crops is also discussed, with a particular focus on those non-native shrub species that could provide erosion control. When carrying out this review, relevant search terms were used across different databases, websites and search engines to find publicly available literature and other sources of published information. As well as providing an overview of erosion control techniques used, knowledge gaps are highlighted and recommendations made for targeted future research to support native forest establishment projects on highly erodible land in New Zealand.

KEY FINDINGS

The key findings within this review are summarised below.

- The majority of Māori land in new Zealand is steep and erosion prone. Tangata whenua have a deep connection to, and mātauranga of, their land which is based in whakapapa. Whakapapa defines a responsibility to exercise kaitiakitanga over natural resources, including the whenua and ngahere. It is important to consider the following aspects when establishing native forest on erodible land:
 - The exercise of mana motuhake or absolute authority (referred to as mana whakahaere in the NPS-Freshwater Management 2020) since most erodible land is Māori land.
 - True and equal partnership with tangata whenua to ensure that mātauranga and iwi-hapū aspirations for the land are captured within planning.
 - The healing potential of Papatūānuku in native forest regeneration and acknowledging that mature native forest takes a long time to establish.
 - Taonga species and the impact that restoration works may have on these, or where these species may be used for erosion control such as bracken fern (*Pteridium esculentum*), and any cultural considerations around their use.
- Plant root systems provide the primary mechanism of reinforcing soil and control erosion. The spread and depth of rooting systems is highly variable between native species. Although root system spread increases with age, root growth may be limited by stony and shallow soils which are commonly present on steep slopes.

- Mānuka is the most common native species used as a nurse crop when planting areas of steep, erodible land in New Zealand. The role of non-woody species that naturally precede mānuka in native forest succession such as ferns and mosses should be investigated. We recommend to further explore hardy ferns such as bracken fern (*Pteridium esculentum*) for their potential use within restoration projects on highly erodible land.
- Restoration approaches that assist natural regeneration, either by attracting birds that eat certain species, or planting seed islands, are significantly more cost effective than planting out bare or pastoral areas in forest.
- Space planted mānuka (2x2-3x3m spacings) is the most common technique to establish natives on highly erodible land within New Zealand. Other techniques were also found to be effective for vegetation establishment to achieve erosion control. Some of these techniques are being used or trialled in New Zealand and others are used internationally and could be applicable to New Zealand. These include:
 - Geotextile coverings
 - Seed islands
 - Drone seeding
 - Space planting (predominantly using exotic species such as poplar and willow)
 - Hydroseeding
 - Plant-microbial remediation
 - Plant-fungal bioremediation
 - Pioneer bracken fern

Where techniques are already being trialled (e.g. drone seeding, seed islands), we recommend that these are monitored as trials progress.

- International techniques for establishing vegetation for erosion control, that are not currently in use to New Zealand include:
 - Live staking
 - Live fascine
 - Brush layering
 - Branch packing
 - Trench packing

These techniques could become applicable to New Zealand native species in the medium to long term, depending on the investment in and results of future research trials.

- New Zealand wide information on suitable native species and costs of their establishment for erosion control is dispersed. A Beta version of a Native plant species selector tool (originally formulated at Manaaki Whenua - Landcare Research) provides ecological information in a relatively friendly format, and could potentially be enhanced for further applications. We suggest that MPI Te Uru Rākau consider testing the latest version of this tool in the context of native afforestation. Other tools such as planting and budgeting, and economic assessment calculators, are already publicly available and could also be further refined or enhanced with default values by region or sub-catchment.

1 Introduction

Aotearoa New Zealand has a high proportion of steep land area (over 60%; (Basher, 2013; Dymond et al., 2006)) much of which is subject to high rates of soil erosion, with 5% of land area classified as highly erodible in 2012 (Stats NZ, 2019). Erosion has a negative impact on the productivity potential of land and also on the quality of freshwater systems (by increasing sedimentation and turbidity). Severe weather events involving large rainstorms have increased the frequency of landslide erosion in New Zealand hill country, depleting valuable soil resources (Dymond et al., 2006; Neverman et al., 2023). Recent impacts from cyclone events such as Cyclone Hale in January 2023 and Cyclone Gabrielle in February 2023, have caused significant landslide erosion of hill country particularly across the Te Tairāwhiti Gisborne and Te Matau-a-Māui Hawke's Bay regions.

High levels of erosion in New Zealand have been influenced by large scale native deforestation by Polynesian and European settlers for the purposes of agricultural and timber production (Basher, 2013). Considerable effort and focus is now underway to restore our native ngahere. Establishing vegetative ground cover is a commonly used method to provide some protection against surface erosion. Closed canopy tall woody vegetation was found to reduce the incidence of landslides during large storms by 70-90% (Basher, 2013). Establishing native forest further enhances biodiversity, cultural and often recreational benefits (Chartes et al., 2020; Suryaningrum et al., 2022).

Nearly 80% of Māori land is steep and hilly, located in Land Use Capability (LUC) classes 6-8 making it highly susceptible to erosion (Awatere et al., 2018). Māori have the right to mana motuhake: authority through self-determination and control over one's own destiny. Māori also hold kaitiaki (guardianship and resource management) responsibilities through whakapapa (genealogy). This review can inform current and future partnerships with Māori for native forest establishment in highly erodible land.

Moderately steep land is defined as having a slope angle of 21-25°, steep land 26-35°. and very steep land > 35° (Landcare Research, n.d.). Establishing native forest on steep, highly erodible land has a number of associated challenges, including access, health and safety concerns (Ngā Uruora Committee, 2013). This is particularly the case where there are slips (England, 2023) and/or unsuitable environmental conditions for plant growth, such as lack of water supply (Ngā Uruora Committee, 2013). The establishment of native plants in New Zealand using techniques such as low density plantings of mānuka and kanuka (Dewes et al., 2022; Marden et al., 2018) and creating seed islands (Tāne's Tree Trust, 2023a) are already being used or trialled for marginal hill country and steep slopes.

This review considers the international techniques and technologies that are used to control erosion on steep slopes and how these may be applicable to New Zealand settings.

1.1 SCOPE

This literature review provides an overview of projects and current research around establishing native forest on highly erodible land in New Zealand and erosion control practices are implemented, as well as a review of successful slope stabilisation techniques used internationally in conjunction with planting.

The scope of the review includes:

- Projects that are current (or recently completed) which have focused on native tree establishment on lands with high erosion susceptibility in New Zealand, their successes and failures, and the impact of methods used regarding erosion control.
- Projects that are focused on erosion land protection through the establishment of native trees (especially taonga species) that are aligned in accordance with mātauranga Māori and kaitiaki principles.
- An overview of nurse crops that are used within these projects, including the potential for non-native shrubs.
- An international overview of successful slope stabilisation techniques and technologies used in conjunction with planting including bioengineering methods of erosion control, and where these are immediately or not as immediately applicable within New Zealand.
- Identification of potential knowledge gaps, and
- Recommendations made for further research that could support future native forest establishment on extremely eroded land in New Zealand.

1.1.1 Out of scope

Topics that are out of scope for this review include the following:

- Projects focused on exotic/non-native species (other than non-native shrubs that are or could potentially be used as nurse crops).
- Projects focused only on native riparian species or restoration of riparian environments. However, those projects that have focused on general stream bank and gully erosion control measures are included with a focus on specific erosion control aspects.
- Projects that focus on native forest establishment on land that is not classified as steep or susceptible to erosion are at times mentioned throughout this review, however these are discussed in depth in a concurrently produced literature review.¹
- Information sources that are unpublished or not publicly available, as well as interviews and primary data collection.

1.2 EROSION SUSCEPTIBILITY CLASSIFICATIONS

A number of erosion susceptibility classifications are in use within New Zealand, and these are described below.

The **Erosion Susceptibility Classification (ESC)** was developed to allow regulatory thresholds to be set when implementing the National Environmental Standard for Commercial Forestry (NES-CF), formerly known as the NES-Plantation Forestry (NES-PF). The ESC is based on erosion data within the New Zealand Land Resource Inventory (NZLRI) and Land Use Capability (LUC) database and has been developed further to capture erosion risk specific to the establishment of plantation forestry (Ministry for Primary Industries, 2017). The ESC categorises land into four classes: very high (red) and high (orange) (land more likely to erode; plantation forestry requires a resource consent), moderate (yellow) and low (green) (land less likely to erode; plantation forestry is a permitted activity) (Ministry for Primary Industries, 2022).

Although the ESC has been developed specifically for plantation forestry, the LUC classes which it is based on have been developed based on potential for pastoral farming. The LUC classes are commonly referred to particularly where land is transitioning to forest from

¹ See literature review report “*Review of current research on native forest establishment*” (WSP, 2023)

farmland. The LUC classifies the ability of land to sustain productivity and captures those factors which are most limiting to production, including erosion potential. LUC classes consist of a class code (1-8), which describes the versatility of the land, a subclass modifier (e, w, s, c), which describes any particular limiting factor to production, and a unit identifier (1,2, ...), which uniquely describes the landform in more detail (Newsome et al., 2008). Highly erodible land is typically classed as LUC 7e or 8e and sometimes 6e.

The **Highly Erodible Land (HEL)** model classifies erosion prone land further into five classes: landslide erosion (high risk – delivery, or high-risk - non-delivery to stream), earthflow erosion (moderate or severe), and gully erosion (Ministry for the Environment, 2019).

Some of the projects and literature included within this review give reference to the classifications described above; however in many cases land is described qualitatively as steep or erosion prone without reference to a classification system. Therefore, this may include areas that are actively eroding as well as those areas that have a high potential to erode.

2 Materials and methods

We conducted a targeted literature review using different combinations of the following keywords: native, indigenous, tree, forest, planting, tree programme, establishment, afforestation, reforestation, regeneration, seedling establishment, Aotearoa New Zealand, erosion, eroded soils, high erosion susceptibility/erosion susceptibility classification, slope stabilisation/techniques, bioengineering/methods/control, erosion control, severe/natural event/climatic events, Cyclone Gabrielle, Māori, kaitiakitanga, taonga, mātauranga, rongōā rākau, ngahere, colonising species/crops/shrubs, nursery/nurse, pioneer, succession.

The databases reviewed included: Google Scholar, Scopus, Science Direct, Scielo.org; and websites: Tane’s Tree Trust, Trees that Count, the MPI One Billion Trees Programme projects, and Google searches. We reached out to various global WSP Practice Area Networks (PANs), including those for Ground Engineering and Sustainable Development, Resilience & Climate Change PANs, who shared resources on bioengineering and slope stabilisation techniques. We also searched the social media platform ‘X’ for recent announcements on bioengineering publications. Project based information is summarised in Appendix A, while the remainder of the document highlights key themes, knowledge gaps and recommendations.

3 New Zealand native forest establishment for erosion control

Exotic species have typically been the preferred option for erosion control as they generally grow, sequester carbon, and colonise bare areas at a faster rate than native species (Phillips, 2005). This focus on exotics has traditionally relegated natives to areas where particular aesthetic or conservation values have been prioritised along with erosion control (Phillips, 2005). However, there has been a resurgence in interest in utilising indigenous species for erosion control to provide multi benefits to water quality and enhance indigenous biodiversity, connecting remnant vegetation (Palmer et al., 2019), while maintaining vegetation on the site through the succession of species (Rey et al., 2019).

Knowledge about native species and their usefulness in erosion control is limited (Phillips, 2005) compared to that of exotic species. For instance, much of the research relevant to understanding the erosion control effectiveness of mānuka, the indigenous species

predominantly used for erosion control, has largely been derived from investigations of ‘stands’ of naturally reverted scrub and/or of individual trees extracted from these stands (Marden & Lambie, 2016). Although there are multiple species available that could perform the same roles in erosion control as commonly used species (Rey et al., 2019), many have not been tested for suitability, limiting present research and practise to a small pool of selected species.

3.1 TE AO MĀORI PERSPECTIVES RELATED TO NATIVE FOREST ESTABLISHMENT ON HIGHLY ERODIBLE LAND

Te ao Māori is a holistic view of the world and universe based on the relational principle of whakapapa, which places Māori people within the environment rather than separate from it (McAllister et al., 2023). Whakapapa connects the physical and spiritual worlds to the cosmological world, connecting Māori people to the sky father Ranginui and the earth mother Papatūānuku, and their children, who are commonly seen as the original kaitiaki (those with responsibility to protect) of the natural environment. Understanding whakapapa allows us to define both the privilege and responsibility of Māori people to benefit from and protect the environment and is therefore the basis of kaitiakitanga (McAllister et al., 2023). Kaitiakitanga is “an environmental ethic and it concerns Māori responsibilities and obligations regarding including land, water, wāhi tapu, and taonga” (Hera Beverland, 2022). Kaitiakitanga should also be defined as “resource management” (Kawharu, 2000). Māori have a “deep rooted connection” with the whenua and over generations have developed considerable knowledge of the ngahere and native rākau species of Aotearoa (many of which are taonga – having cultural importance to Māori), which is captured within mātauranga (Māori knowledge) (French Armstrong, 2022).

Over 60% of Māori owned land is steep and erosion prone (Awatere et al., 2018) and Māori landowners in Te Tairāwhiti region identify erosion control as a key challenge (Pohatu et al., 2020). The concept of mana motuhake or absolute authority is referred to as mana whakahaere in the National Policy Statement Freshwater Management 2020 (Ministry for the Environment, 2023) and is fundamental to progress any project that involves tangata whenua in native forest establishment, including those on highly erodible land. In practice, partnership guided by Te Tiriti o Waitangi/The Treaty of Waitangi, requires “adequate resourcing for all partners contributing to the collaborative process” (Harmsworth et al., 2016). Equal partnership with tangata whenua would also ensure that mātauranga and iwi-hapū aspirations for the land are captured within planning.

Here we summarise the Māori cultural aspects of the literature and projects included within this review.

Dewes et al. (2022) highlight the healing powers of Papatūānuku; entrusting the natural reversion and maturing of ngahere at the speed that nature allows (recognising that this may take 100 or more years for regeneration of complex ecosystems) rather than forcing rapid change. On naturally reverting marginal hill country sites, this is observed through the germination of numerous mānuka and kānuka seedlings once stock exclusion has occurred. Over time, this healing cover of mānuka and kānuka shrub thins down to 2-3 metre spacings (as mimicked in the Tīmata method). At 30-50 years, the diffused light that is allowed to reach the ground allows for the germination of other coloniser species, eventually succeeded by second and third tier broadleaf, conifer and podocarp species (Dewes et al., 2022).

A restoration project led by Pūniu River Care Inc. aims to improve the mauri of the waterway, restore tuna habitat and terrestrial biodiversity of the Pūniu River, which is subject to high levels of erosion and sedimentation (Pūniu River Care, 2021). This is being achieved by

fencing off stream banks and marginal sidling areas, completing erosion protection works and planting native trees in erosion prone areas including streambanks and gullies. Species such as koromiko (*Hebe salicifolia*), mānuka (*Leptospermum scoparium*), harakeke (*Phormium tenax*) and kawakawa (*Piper excelsum*) have been planted for bank stabilisation and biodiversity corridors, while additionally providing rongoā rākau (traditional plant medicine). Restoration of the Pūniu River is of significant spiritual value to the tangata whenua. Along the process of restoration kaimahi have felt a sense of re-connection to their whenua and tūrangawaewae ('a place to stand'). One of the forms of measuring success for the project is measuring the health of the waterway. Health of the waterway can be measured by the abundance and quality of freshwater kai such as tuna (freshwater eels), kōura (crayfish) and freshwater mussels. Community engagement is critical for this project, as its success is reliant on the cooperation and engagement of 31 landowners allowing the work to be completed on their land. The relationship built with these landowners has led to a number of other community members making contact with Pūniu River Care to further restoration beyond the current scope of these projects. They have also created a marae-based restoration guide to enable other organisations to undertake similar restoration activities.

Bracken fern (*Pteridium esculentum*) is of historical significance to Māori (Bray, 1991). Bracken was an essential component of a traditional Māori diet with the rhizome being a primary source of starch. Bracken growing on deep soils were ideal for harvesting as these tended to grow larger rhizomes. The potential of bracken fern to provide erosion control on highly erodible land is discussed further in section 4.3.7 *Pioneer bracken fern*.

Engagement with mana whenua forms a key part of the implementation plan for the Waingake Transformation Programme in Te Tairāwhiti (White & Foreman, 2020). The programme, led by Gisborne District Council in partnership with mana whenua Maraetaha Incorporated and Ngai Tāmanuhiri, is aiming to restore 1,200 hectares of pine plantation with much of this area considered steep and erodible. A tangata whenua / Māori engagement plan has been developed to ensure that meaningful inputs are included from local iwi and hapū who have an understanding of the history and cultural importance of the site (England, 2023; White & Foreman, 2020).

3.2 NATIVE PLANT ROOTING CHARACTERISTICS

When considering plants for erosion control, the rooting characteristics of a species has a significant influence on its efficacy, as roots are the primary mechanism for mechanically reinforcing the soil (USDA, 1992). Roots and below ground characteristics of indigenous species have historically received little attention, with studies generally involving few species with limited age range (Phillips, 2005).

(Marden et al., 2018) reported values for root structure for selected native tree species. They noted two types of root systems, tap-rooted and plate-rooted. Tap rooted species included *Agathis australis*, *Dacrycarpus dacrydioides*, *Vitex lucens*, *Podocarpus totara* and *Dacrydium cupressinum*. The authors found that *Agathis australis* was the earliest to develop roots that extended deeper than the other trialled species (0.3 m) at year three. At year five, *Podocarpus totara* produced the longest lateral roots extending up to 2.2 m. *Vitex lucens* presented the greatest mean root spread (2.5 m). Plate-rooted species studied include the conifers *Prumnopitys taxifolia* and *Prumnopitys ferruginea* and the broadleaved *Alectryon excelsus*. Their compact root systems consist of abundant fibrous and several short, gnarly, lateral roots of less than 1 mm diameter. The mean maximum root spread of both *Alectryon excelsus* and *Dacrycarpus dacrydioides* (1.7 m) was significantly larger than the root spread of *Prumnopitys taxifolia*, *Prumnopitys ferruginea* and *Dacrydium cupressinum* (ranging from

1 m to 1.2 m and not significantly different from each other) (Marden et al., 2018). Lateral roots of native trees interlock with each other and form a net that could support erosion control.

In literature reviewed by Phillips (2005), all native species typically had shallow roots, confined to the first 31 cm of soil by year five. However, a later study by Marden et al. (2018) extended this research to specify that *Prumnopitys taxifolia* (matai), *Agathis australis* (kauri), *Prumnopitys ferruginea* (miro), *Dacrycarpus dacrydioides* (kahikatea), *Dacrydium cupressinum* (rimu) and *Alectryon excelsus* (titoki) roots were contained in the first 0.5m of soil. *Vitex lucens* (puriri) and *Podocarpus totara* (tōtara) were deeper rooting with 90% of the rooting being within the first 0.5m of soil.

For older stands of mānuka (13-50 years), rooting depth was 0.5 m for stoney soils and 0.8 m for sandy soils (Phillips, 2005). Kānuka however, was shown to reach a maximum depth of 1.5-2.2 m between six and 32 years old. The study concluded that rooting depth was primarily limited by soil stoniness and depth rather than tree age. Further research into 25-year-old cabbage trees growing in alluvial gravels estimated rooting depth to be around 2m deep. A summary of the literature by Phillips (2005) concluded that New Zealand's tallest podocarp forest species rarely have a rooting depth that exceeds 2m.

More recent research by Marden & Lambie (2016) found that the mean maximum root spread of the lateral roots of four year old mānuka (*Leptospermum scoparium*) at Lake Tutira (Hawke's Bay) was about 3.5 m, while maximum rooting depth was about 1.1 m. Although there were differences in maximum rooting between different erosion landforms, it was not significant. Root biomass was highly variable over different erosion landforms and compromised of <20% of total plant biomass.

3.3 PIONEER/NURSE CROP SPECIES & THEMES

While natural regeneration is generally considered too slow for practical erosion control measures, it is useful to consider a range of species involved in natural succession processes. When the landscape is disturbed and nature is allowed to regenerate, vegetation develops through a series of stages (Porteous, 1993). Generally, the first species to colonise a bare, soil less landscape are lichens, followed by mosses and small herbs. Over time these non woody species build fertility and organic matter (Phillips, 2005), allowing hardy shrubs and trees to become established (Porteous, 1993). These pioneer woody species create shade, shelter and attract birds carrying other seeds, resulting in secondary succession, with taller slower growing species growing above the woody pioneers, eventually replacing them.

Heavily eroded environments, such as the steep rocky faces on the side of a mine, are first colonised by mosses which increase organic matter and act as a nurse crop for subsequent succession of vascular fern like species (Phillips, 2005). Research and technology is ongoing, looking at the ability to establish moss via hydroseeding (see section 4.3.4 *Hydroseeding*) and which species to use in certain landscapes. Species such as Bracken fern (*Pteridium esculentum*) is promising for its colonizing ability, hardiness and requirement for full sun (Fern Factor, 2019; McGlone et al., 2005) . Other species may be promising in specific environments, for example kiokio (*Blechnum novaezealandiae capense*) is promising for places like roadsides due to its moderate tolerance of management and ability to resist invasion of other species (Phillips, 2005).

Mānuka (*Leptospermum scoparium*) and kānuka (*Kunzea ericoides*) are common native woody pioneers across much of New Zealand (Porteous, 1993). They attract mycorrhizal fungi which can begin conditioning the soil (Dewes et al., 2022) and provide ideal conditions

for the establishment of succession species in their understory (Porteous, 1993). A number of projects mimic this natural process, and assist natural regeneration by planting mānuka in a grid to establish a nurse crop (Dewes et al., 2022; Marden & Lambie, 2016; Tāne's Tree Trust, 2023b). Where landforms were eroded, such as slips, it was recommended not to rely on regeneration and plant 100% of the area to provide erosion control sooner than natural regeneration would (White & Foreman, 2020).

The addition of exotic poplar and willow poles can provide rapid land stabilisation (England, 2023; White & Foreman, 2020), reducing erosion and assisting in the establishment of native pioneer species. When native pioneer species are successfully established and the exotic poles provide no additional benefit in terms of erosion prevention, then the poles can be removed to allow the natives to fully occupy the site.

Other native woody pioneer species identified by Ngā Uruora Committee (2013) for the Perkins Farm escarpment restoration project are pohuehue (*Muehlenbeckia complexa*) and tauhinu or cottonwood (*Ozothamnus leptophyllus*). Cottonwood requires grazed pastures to establish, as thick pastures inhibit germination. Canopy cover of pioneer mānuka planted at 1,000 trees/ha was expected to be 7-8 years for ideal sites (Marden & Lambie, 2016). Slower establishment due to competition from grass and sedges at wetter sites, and growing challenges at higher altitude and more exposed erosion sites result in canopy closure being greatly delayed, even at higher planting densities. The Tīmata method explained in Dewes et al. (2022), mimics pine plantation methods, by planting forestry grade seedlings at 3 m by 3 m (1,100 plants/ha) to 2 m by 2 m (2,500 plants/ha) for a significant cost saving (see 3.4 *Economics of establishing natives for erosion control*). Plant mixtures vary, with dry sites typically constituting approximately 50% kānuka, 20% mānuka. Cooler and wetter sites would shift to 50% mānuka and 20% kānuka.

The next step for succession beyond woody pioneers such as mānuka, is the introduction of a diverse range of secondary pioneers or tall slow growing species. When naturally reverting, mānuka can go through a thicket stage where competition for resources, namely light, limits growth, as well as the establishment of other species (Porteous, 1993). This will subside over time as the plants mature and thin to a final density, or it can be sped up by thinning or checking.

If native forests are nearby, seeds deposited by native birds can germinate in the understory and succeed the mānuka and kānuka nurse crop. To speed up this process, the Tīmata method includes 30% bird loving species to draw native birds to the area spreading seeds as they move. Birds play a major role in the dispersion of seeds from many indigenous lowland forest species (Porteous, 1993). They are responsible for spreading the seeds of all podocarp species. The New Zealand pigeon (kererū; *Hemiphaga novaeseelandiae*) is a very important species for dispersing seeds due to their large appetite and ability to transfer the relatively large seeds of some species. Planting species that kererū, and other seed dispersing bird species can eat, promotes speedy regeneration of native forests, due to the swift introduction of non-pioneer woody species from seed dispersal. A recent study showed that pioneer tree species in New Zealand 'did not rely on animal or bird dispersal, had smaller leaves, and a chemistry that made them unpalatable to browsers', but 'later arrivals had seeds brought in by birds and were more palatable' (Mason, 2023).

If established native forests are not nearby, then seed islands can provide an opportunity to facilitate regeneration. Tāne's Tree Trust (2023a) planted small groves of diverse, intensively managed native trees and shrubs to utilise a greater diversity of seed dispersal via wind and birds across a broad area. Seed islands are more cost effective than blanket planting and

utilises the concept of working with nature, enlisting the help of birds and wind. The Waikereru Ecosanctuary Seed Island Project has established 20 seed islands today, comprising of 15-20 plants in each, filling open grass areas under gaps in the canopy (Tāne's Tree Trust, 2023a). The Perkins Farm Escarpment project has utilised the same concept and stated that spacings between trees within the islands should be 2 m in sheltered sites and 1-1.5 m in exposed sites at the top and edges of gullies. This project utilised flax (*Phormium tenax*) and other colonisers at the top of slopes to act as another seed source (Ngā Uruora Committee, 2013).

3.3.1 Non-native shrubs as nurse crops for erosion control

Although non-native shrubs were not found to be used or mentioned within the projects and research included within this review, a concurrently published literature review¹ discusses the potential for gorse (*Ulex europaeus*) and broom (*Cytisus scoparius*) to be used as nurse crops. Although these species are commonly viewed as pest species to eradicate, they have been used successfully for areas of native forest regeneration at Hinewai Reserve on the Banks Peninsula (Wilson, 2003). The concurrent review¹ also highlights the potential for tagasaste (*Cytisus proliferus*) and a range of other non-native shrubs identified in (Williams, 2011) which could potentially act as effective nurse crops for native forest establishment, but may require further research to confirm their appropriateness. In addition to further exploring the potential of these species for nurse crops, it is our recommendation that their potential for erosion control is also investigated.

3.4 ECONOMICS OF ESTABLISHING NATIVES FOR EROSION CONTROL

Native establishment costs are considered to be highly uncertain and vary by location, establishment methods, species and various other factors, including pest control (Climate Change Commission, 2021). The lowest cost method found in this review was the Tīmata method, which can cost \$6,000/ha, significantly less than the \$20,000-\$30,000/ha usually associated with densely planted high grade natives (Dewes et al., 2022; Palmer et al., 2019). The practices utilised with the Tīmata method can generate revenue via honey from the mānuka and kānuka (Dewes et al., 2022; Marden et al., 2020; Palmer et al., 2019), as well as via carbon credits from the ETS (Dewes et al., 2022; Palmer et al., 2019). When honey production is a key driver, mānuka can become a monocrop to ensure high UMF rating and therefore, revenue.

Palmer et al. (2019) reported that the costs of planting indigenous species on eroded hill country can be high (up to \$30,000/ha) with potentially unreliable results due to uncertain growth rates. In the early stages economic value can be derived from native afforestation via mānuka oil production and high UMF honey on warm, sheltered free draining sites that receive little summer rain and wind during flowering (Palmer et al., 2019). Mature systems have value in providing ecosystem services but the best economic potential is using podocarps such as tōtara or rimu for timber; however this option is limited to the most favourable sites (Palmer et al., 2019). Long harvesting rotations of these native timber systems have a significant effect on economic returns such as net present value (Palmer et al., 2019). While there could be an opportunity to utilise exotic species as a nurse crop for native forests, thus benefiting from higher carbon sequestration units from the New Zealand ETS compared to natives, several knowledge gaps remain about how to transition exotic forests into native species (Forbes Ecology, 2021). Ongoing investigations (2022-2027) aim to produce best-practice transitional forestry and monitoring guidelines to fill these gaps (Tāne's Tree Trust, 2023b).

Publicly available tools for estimating native forest establishment costs are limited, with a few exceptions such as a recent survey of actual costs of the main native forest establishment methods (Forbes Ecology, 2022) and Tāne's Tree Trust calculator for planting and budgeting. This calculator provides some default values for seedlings of native shrubs and trees (Tāne's Tree Trust, 2022b). The tool requires to input data on area, spacing, species, and costs data of seedlings, site preparation and planting, weed control, fencing and other silviculture costs. The default values can be updated with up-to-date location specific information from nurseries (e.g. seedlings costs) and other sources (e.g. labour costs). Their economics calculator estimates net present value of native trees considering expected income from carbon and wood harvesting and user assumptions on costs and frequency of pest control and harvesting, and transport costs (Tāne's Tree Trust, 2022a).

3.5 KEY LESSONS

A number of key themes of lessons emerged across the different projects and are described in this section.

Final stocking rate of mānuka was a key factor in time till canopy closure (Marden & Lambie, 2016) and efficacy as an erosion mitigation measure. Marden & Lambie (2016) stated that there was a large variability in mortality between sites with differing erosion severity. They recommended planting at densities that will achieve desired final stocking rate, allowing for mortality on sites affected by past and current erosion.

The protection of new seedlings within planted or natural regeneration approaches is another key theme. Introduced animals can cause significant damage to indigenous forest by directly eating plants or seedlings and seeds restricting regeneration. Livestock have a similar effect, browsing and trampling plants and seedlings, as well as physically damaging trunks and branches of larger trees. Livestock, including wild deer, must be excluded with an appropriate fence or by other means to ensure successful and timely regeneration (Ngā Uruora Committee, 2013; Porteous, 1993). Wild possums, mice, and rats have a negative effect on native forests by consuming seeds and vegetation and negatively impacting native bird populations, therefore restricting seed dispersal and subsequent regeneration. Mustelids, stoats, ferrets and cats do not directly damage indigenous fauna but they can also negatively impact native bird populations and should be controlled with either poisoning, trapping, shooting or other appropriate means.

Weeds affect forests differently depending on their mode of growth (Porteous, 1993). Weeds can smother, strangle, compete or suppress native forest, restricting or stopping growth. Most common weeds are associated with competition for resources but some form less desirable growing conditions for seedlings, restricting regeneration. Such species are pampas, wattle and boxthorn, as identified by (Ngā Uruora Committee, 2013). However, some weeds can form desirable microclimates for seedlings and can be utilised as a nurse crop before either being removed or out-competed by succeeding species (Porteous, 1993).

The health and safety of individuals responsible for establishing and managing native forests is a risk. The Waingake 2023 program was impacted by cyclones (Cyclone Hale and Gabrielle) and other severe weather which required amendments to the planned seasonal planting, to avoid access issues and ensure worker health and safety as land movement was ongoing in some of the planned planting areas (England, 2023). Significant numbers of seedlings were lost either directly to slips or where contractors were unable to complete release spraying. These areas require replanting and could benefit from additional erosion control measures to avoid similar outcomes in future adverse weather. Drone seeding is being

trials by Envico Ltd on slips where it could prove a cost effective and safer option for regeneration in these areas (England, 2023).

In the mostly LUC 7e and 8e land within the Waikakariki and Hairpin Gullies of the Perkins Farm escarpment (Kapiti Coast), rank grass (overgrown, tussocky) growing on fertile soils reaching ~0.5m in height was suggested as being effective at reducing damage from storm events, by absorbing water and resisting surface flow (Ngā Uruora Committee, 2013). Pohuehue (*Muehlenbeckia complexa*) was observed to naturally succeed over the grass and will further increase the absorption and resistance to flow. A large flooding event in 2003 caused significant landslides, gully erosion and debris flood deposits, and forested areas were observed to have less erosion than less vegetated areas. Planting poplars on the edges and heads of eroding gullies has been suggested but the report does not recommend poplars due to the strong salt laden winds restricting growth, instead recommending native vegetation as a better option. They also recommend a combination of rank grass and streamside plantings within valley areas. In the adjacent areas of the Paekākāriki Escarpment, zoned as ‘very high erosion susceptibility’ in Kāpiti Coast District Council plan, propinqua (*Coprosma propinqua*) has naturally colonised these slopes. This is evidenced in historical pictures that show how the plant has spread. It is not recommended to manually plant these areas as they are very steep (difficult to access safely) and have a limited water supply, but some natives (flax, other colonisers) could be planted at the top for a seed source to support natural regeneration. The project has suggested building gates across the valleys to stop movement of loose material during large flood events. Vertical rails and tyres used within the Hairpin Gully were shown to be partly effective. The report suggests that “engineers should investigate the feasibility, costs and benefits of gates built at intervals across the valley floor, preferably just downstream of actively eroding side gullies” (Ngā Uruora Committee, 2013).

4 Slope stabilisation techniques

Approximately 5% of New Zealand’s land area is classified as highly erodible in 2012 (Stats NZ, 2019). Erosion processes are naturally high in New Zealand as a result of steep slopes, weak underlying bedrock, high rainfall and the prevalence of high-intensity rainstorm events. Erosion and sedimentation are natural processes largely driven by climate, geology and soil type; however they are being exacerbated by human activities such as deforestation and land use change to pastoral farming. Due to the high proportion of steep land in Aotearoa New Zealand, slope stabilisation techniques are vital for protecting soil resources, freshwater catchments, and infrastructure. In 2001, it was estimated that the economic cost of soil erosion and sedimentation was \$126.7 million per annum to New Zealand’s economy (Phillips et al., 2020). There are some bioengineering techniques applicable to New Zealand, while there are others that are yet to be implemented in a New Zealand context and these are covered in section 4.4 *Techniques not immediately applicable*).

4.1 BIOENGINEERING

Bioengineering is the application of biology principles and engineering tools to create viable products that can be used in the field. Soil bioengineering is an applied science that combines structural, biological, and ecological concepts to construct living structures (plant communities) for erosion (Meadows et al., 2002). The most common uses of bioengineering include soil surface protection against erosion, bank stabilisation, maintaining biodiversity and improving drainage functions (Salter et al., 2020). The goal is to establish plant structures while stabilising erodible landscapes. Bioengineering is intended to compliment nature, using locally sourced plant materials and using engineering materials where appropriate. Many bioengineering techniques can be used in conjunction with one another.

4.2 OVERVIEW OF TECHNIQUES

An overview of the slope stabilisation and bioengineering techniques covered within this review, including their key advantages and disadvantages, is provided in Table 1.

Table 1: Slope stabilisation and bioengineering techniques used for erosion control, their key advantages and disadvantages and applicability to New Zealand.

Bioengineering technique	Key advantages	Key disadvantages	Applicability in NZ	References
Afforestation	<ul style="list-style-type: none"> • Potential for large reductions in sediment losses from gully systems 	<ul style="list-style-type: none"> • Expensive to implement • Vulnerability in establishment i.e. moisture and grazing animals • Long lag phase for effectiveness of slope stabilisation 	Yes	(Marden et al., 2011)
Space planting	<ul style="list-style-type: none"> • Allow animals to graze beneath trees • Provide shade and shelter for grazing stock 	<ul style="list-style-type: none"> • Effectiveness based on planting density 	Yes	(Phillips et al., 2020)
Geotextile covering	<ul style="list-style-type: none"> • Immediate reduction in erosive energy • Can be used on very steep slopes 	<ul style="list-style-type: none"> • Soil contamination from materials used • Relatively expensive to implement 	Yes	(da Luz et al., 2021) (Gröner & Roduner, 2018)
Hydroseeding	<ul style="list-style-type: none"> • Rapid covering of large slip areas 	<ul style="list-style-type: none"> • Specialised equipment required 	Yes	(Salter et al., 2020)
Plant-microbial remediation	<ul style="list-style-type: none"> • Increase soil organic matter and soil fertility 	<ul style="list-style-type: none"> • Low capital investment • No secondary pollution 	Yes	(Shen et al., 2023)
Plant-fungal bioremediation	<ul style="list-style-type: none"> • Increase soil organic matter • Enhance availability of nutrient to plants 	<ul style="list-style-type: none"> • Success dependent on climatic conditions 	Yes	(Elsakhawy et al., 2022) (Schwarz et al., 2020)
Pioneer bracken fern	<ul style="list-style-type: none"> • Promotes indigenous forest regeneration • Colonises in wet areas 	<ul style="list-style-type: none"> • Young fronds can be poisonous to cattle and horses 	Yes	(Fern Factor, 2019) (Bray, 1991)
Live staking	<ul style="list-style-type: none"> • Intercept rainfall and reduce runoff 	<ul style="list-style-type: none"> • Only effective once rooting structure established 	No	(USDA, 1992).

Bioengineering technique	Key advantages	Key disadvantages	Applicability in NZ	References
	<ul style="list-style-type: none"> • Simple and inexpensive 	<ul style="list-style-type: none"> • Requires moisture for establishment 		
Live fascine	<ul style="list-style-type: none"> • Trenches immediately trap soil and sediment • No earthmoving required so can be used in remote areas • Provide food and fish habitat 	<ul style="list-style-type: none"> • Labour intensive process 	No	(USDA, 1992).
Brush layer	<ul style="list-style-type: none"> • Prevents soil erosion and stabilises bank by creating shorter slopes • Provides fish habitat and native vegetation • Reestablishes healthy riparian zone functions 	<ul style="list-style-type: none"> • Relatively expensive • Requires expertise and special machinery • Labour intensive process • Only effective on upper slopes 	No	(USDA, 1992).
Branch packing	<ul style="list-style-type: none"> • Almost immediately stabilises soil • Relatively inexpensive • Provide food and fish habitat 	<ul style="list-style-type: none"> • Labour intensive process • Requires large amount of plant material 	No	(USDA, 1992).
Trench packing	<ul style="list-style-type: none"> • Slows and reduces the erosive energy of moving water and wind 	<ul style="list-style-type: none"> • Labour intensive process 	No	(USDA, 1992).

4.3 TECHNIQUES APPLICABLE IN NEW ZEALAND

4.3.1 Afforestation

Afforestation is the establishment of a forest or a stand of trees in place of bare ground and the term reforestation refers to establishing forest in a location where it previously existed. Case studies across New Zealand and around the globe have indicated a reduction in sediment losses where afforestation has been successful on erodible land. On the East Coast on the North Island in New Zealand, reforestation has reduced sediment yield in gully systems by 33%, 17% and 20% in the Waipaoa, Waiapu and Uawa catchments, respectively (Marden et al., 2011).

Trees are most vulnerable in the early seedling stage, to successfully establish they need to be protected from numerous adverse events. Seedlings should be planted where there is

sufficient moisture or the ability to irrigate. Seedlings should be protected from animal browsing, recreational activities, frost heaving, erosion, and washout processes to ensure seedling survival (USDA, 1992). Tree seedlings are often vulnerable to browsing during establishment, therefore it is important to control pest animals and exclude stock from newly planted areas. By planting native or exotic seedlings, gullies are protected in the short term (within weeks), as roots explore the soil soon after planting, compared to exotic cuttings, which must form their own root systems, usually leading to a longer establishment phase (months) (Meadows et al., 2002). Planting trees causes minimal site disturbance and enhances the conditions of nearby soil surface for natural colonisation of vegetative species. It can take at least five years for planted trees to significantly contribute to slope stabilisation, requiring complete canopy cover to reduce erosion processes from rainfall (Salter et al., 2020).

Diversity of plant species was seen as a driving factor of reduced erosion in Switzerland due to resilience to weather events as well as any pests and pathogens that may weaken the trees (Schwarz et al., 2020). In addition, all species selected need to be adapted to the specific site to ensure successful establishment required for erosion control. Clinton et al. (2009) cited in (Satchell, 2018) identifies the following traits of ideal tree species for erosion mitigation on hillslopes: Tolerance to New Zealand's soils and climatic conditions; easy to establish; an extensive root system that can tolerate wet conditions and even burial in aggraded gullies; capable of regenerating or coppicing freely; long lived; no potential to become a pest; production of high-quality timber of sufficient value that could be partially harvested.

Age and density of scrub influence landslide occurrence on steep slopes. In Cyclone Bola, landslide occurrence reduced by 65% in 10-year-old scrub when compared with pasture and this increased to a 90% reduction in 20-year-old scrub (Phillips et al., 2020). The size of the gully can also have a significant impact on the probability of the gully stabilising. Stabilisation was more likely to occur for smaller gullies (Marden et al., 2011). Afforestation can be used on its own as a bioengineering technique or it can be used in conjunction with other strategies mentioned in this section of the report (USDA, 1992).

Phillips (2005) recommended to explore the use of native plants and their roles in erosion and sediment control, understanding which plants are best for which roles, and in what combinations are possible given desired outcomes. These roles include root reinforcement, sediment stripping from runoff, groundcover expansion, and fast establishment. The author also highlighted a knowledge gap about understanding the performance of plant species for functional uses outside of their ecological niches.

Local regional councils, such Hawkes Bay Regional Council, often have lists of suitable species for erosion control available on their website. However, tools for selecting native plant species for erosion control are lacking. Through this review, we identified a Beta version of a New Zealand wide Native plant species selector tool that includes species for highly erodible land (Colin Meurk, personal communication). The tool provides limited ecological information in a relatively friendly format that could be enhanced for further applications once knowledge improves (see Appendix B). While the tool is currently available for testing only, investment could support an enhanced user interface, maintenance, and promotion costs. Other tools such as calculators for planting and budgeting, and economic assessment, are already publicly available and could also be further refined or enhanced with default values by region or sub-catchments (Tāne's Tree Trust, 2022a, 2022b).

4.3.2 Space planting

Space plantings (also commonly called space pole planting or soil conservation trees) are typically used on land where eroding forces from landslides, gully erosion and earthflows are common. In New Zealand, space planted trees are widely used on hill country to reduce the incidence of shallow landslides, usually triggered by extreme rainfall events (Schwarz et al., 2020). Tree roots and collective root mass is the main driver of effectiveness of space-plantings on slopes. Effective erosion mitigation occurs where individual tree roots interlock and become a collective root mass capable of reducing the incidence and severity of landslide occurrence and other mass-movement erosion types. Space-planted poplars (*Populus* spp.) and willows (*Salix* spp.) are the most common erosion and sediment control plants in New Zealand, particularly on hilly pastoral land. This is because they can be established as poles in the presence of grazing animals, and are appropriate for the control of landslide, earthflow, gully and streambank erosion (Phillips et al., 2020). On moderately unstable hill slopes, the trees are planted 10-20 m apart, while on an actively eroding slope, tree can be planted 5-6 m apart. Following a significant storm event in the Manawatu region in 2004, areas that had space planting established had a 39% reduction of landslide area when compared to the pastoral area without trees.

In New Zealand, natural regeneration of kānuka and mānuka can also be used as an erosion mitigation measure on steep hill country. Natural regeneration of mānuka has been shown to result in effective erosion mitigation sooner than space planted manuka (2x2m - 3x3m spacings) due to significantly higher plant density and therefore, root occupancy, achieving an effective root mass (Marden & Lambie, 2016). Space planted mānuka is not an effective erosion mitigation until significant root masses develop beneath the ground surface, interlocking individual tree roots. Up until this point, space planted manuka is susceptible to storm influences. Further research is needed to determine suitable planting density of mānuka for erosion control (Marden & Lambie, 2016).

Space planting also allows for animals to graze beneath the tree canopy; therefore it does not remove effective farmable land. In addition to soil conservation, the trees can also provide shade and shelter for livestock. Excluding stock and or providing plant guards for newly established trees is essential to avoid damage. Space planting can reduce erosion of a similar magnitude to closed-canopy vegetation (afforestation), but the effectiveness is highly dependent on successful establishment of the trees and subsequent maintenance (Phillips et al., 2020).

4.3.3 Geotextile coverings

Geotextile coverings or ‘geomats’ are spread on the soil surface to assist in the establishment of vegetation. They can provide passive protection against erosion in the short term before they become synergistically entangled with vegetation, reinforcing the slope over the long term (da Luz et al., 2021). Geomats immediately reduce the energy impact of raindrops on the soil surface as well as the erosive capacity of surface runoff. Soil particles, as well as other organic matter are retained in the covering helping to rebuild the nutrients stability of the surface and supply nutrients to the surrounding environment. To ensure the success of geomats on very steep slopes, they must be heavily reinforced to the soil. Geomats have been increasingly used for the protection of slopes and margins due to their low cost, simple and rapid construction.

The material of geotextile coverings is typically synthetic. However, natural fibre-based options are in use such as those made from jute or coconut coir (da Luz et al., 2021; Gröner & Roduner, 2018). Naturally biodegradable geotextile mats are preferable as they will

eventually break down in the environment, however, mats made of synthetic materials such as polypropylene offer the advantages of being lighter weight and having good retention properties (Gröner & Roduner, 2018). When combined with hydroseeding, erosion control mats made of polypropylene are very effective at preventing erosion. Covering selection is important to consider as some coverings can begin to sterilise the soil surface if vegetation is not established early. Black variations of geotextiles can heat up in the sun and reduce plant growth. Materials that are colour matched to the soil will not heat up as much and will be less of a visual impediment compared to darker variants (Gröner & Roduner, 2018).

Within New Zealand, a range of geotextile covering products are being trialled by EOS Ecology in Banks Peninsula (Canterbury region) for erosion control and establishing native plants on the cut faces of roadsides (McMurtrie, 2020). This included two rolled products (mats), two sprayed mulch products (hydroseeding, see section below) and one rolled and sprayed combination, with native species plug planted into these coverings (see Figure 1). Results were not available at the time of this review; however it is recommended that these results are sourced to determine which products were successful. The geomat product MacMat-R® developed by Geofabrics has also been used for an exposed coastal site in Whakatane (Bay of Plenty region) to prevent surface erosion along a roadside, however for this trial grass was seeded rather than native plants (Geofabrics, 2011). This product could also prove useful for instances where native plants are established on erodible slopes.



Figure 1: Geotextile products being trialled in Banks Peninsula by EOS Ecology (McMurtrie, 2020).

4.3.4 Hydroseeding

Hydroseeding is a process whereby a mixture of seeds, binder, mulch and fertiliser is sprayed directly on to a surface using specialist machinery. Hydroseeding can quickly give rapid covering of large areas once the seeds have germinated. Significant capital investment is required for hydroseeding, including specialist machinery, materials and skills. Care is required when undertaking hydroseeding as applying the mix too thickly can result in germinated seedling roots not reaching the soil surface, failing to have any long-term erosion control (Salter et al., 2020). Environmental suitability is important for hydroseeding as steep and rocky slopes can be hard for the seeds to establish in due to the lack of soil. It is considered best practice to use seed mixes made up of locally-sourced plant species to ensure the seed banks can better adapt to the surrounding environment. Hydroseeding is one of the

key techniques for recovering sites after mineral mining (Rocha Martins et al., 2020), hence it has potential for recovering bare soils on highly erodible land.

4.3.5 Plant-microbial remediation

The application of microbial agents can be applied to the soil to improve subsequent plant growth and resistance (Shen et al., 2023). These can increase the content of soil organic matter, improve soil fertility and diversity, and purify the polluted soil (it is noted that the source does not clarify what is meant by polluted here). Some microbial agents can promote microflora richness, enzyme activity and improve the plant root's ability to absorb, fix and transform nutrients into plant available form. Plant-microbial remediation is widely used in China due to its low capital investment, simple operation and no secondary pollution (Shen et al., 2023).

4.3.6 Plant-fungal bioremediation

Bioremediation refers to the process in which microorganisms are either naturally or deliberately introduced to an area to create a more desirable environment for growing plants (Elsakhawy et al., 2022). Introducing fungal species onto erodible land can have direct and indirect benefits for erosion control. Fungi can directly reduce erosion by binding to soil particles, exuding compounds such as glomalin and polysaccharides which assist in forming soil aggregates and organic matter (Elsakhawy et al., 2022). These compounds described above not only boost soil organic matter but also enhance the bioavailability of soil nutrients thereby assisting plant growth. This effect was quantified in Schwarz et al. (2020) where soil erosion under plants inoculated with ectomycorrhizal fungi was 20% lower than plants without inoculation (Figure 2).

Fungi could be introduced in restoration sites within New Zealand to reduce surface erosion. Adding fungi into seedling mixtures with soil is an economically affordable way to use this technique (Schwarz et al., 2020). In the short term, fungi can considerably reduce surface erosion, improving the growth of vegetation and protect the vegetation from pathogens. It is important to ensure that fungal species are well adapted to local climatic conditions to ensure the success of this technique.

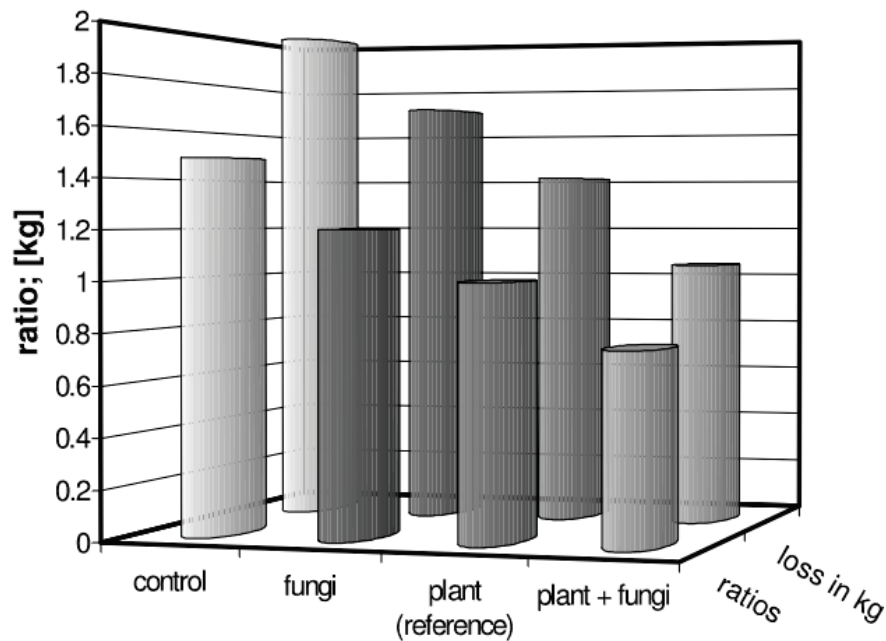


Figure 2: Reduction of erosion rate compared with a reference sample comparing the effects of plants (*Salix* spp.) and fungi (mycorrhizal species) (Schwarz et al., 2020).

4.3.7 Pioneer bracken fern

Bracken fern (*Pteridium esculentum*) is an indigenous plant to New Zealand that is effective in preventing erosion and promoting indigenous regeneration (McGlone et al., 2005). Bracken only persists in natural landscapes where it has full sun (Fern Factor, 2019) and dominates disturbed ground by suppressing the exotic, woody, weed and grass species (McGlone et al., 2005). McGlone et al. (2005) stated that bracken was nearly as effective as forest cover in reducing erosion, quoting that river sedimentation from the Tutira catchment was five times lower when the catchment was dominated by bracken post the clearing of native bush compared to open pasture. Bracken is a successional species, with deeply buried fibrous rhizomes making them fire resistant and able to exploit a wide range of soils with efficient nutrient uptake. Bracken forms one of the finest possible seed beds (Fern Factor, 2019) promoting indigenous forest regeneration (McGlone et al., 2005). Further research needs to be undertaken to determine techniques for establishing Bracken fern and factors influencing the regeneration of native species under a bracken fern canopy (P. Micheal, personal communication, November 21, 2023).

The most promising aspects of Bracken fern is its ability to colonise an area once established, prepare a seed bed for successive indigenous species, and die off once shaded. This pioneer ability is its ecological niche, and it does so by spreading rhizomes and billions of wind spread spores. Spores offer a unique opportunity to spread bracken cost effectively and timely at scale if future research can identify a successful method to mimic nature (P. Micheal, personal communication, November 21, 2023).

Bracken fern has a significant ability to produce biomass and thus sequester carbon, second only in the pioneer species to *Pinus radiata* (Bray, 1991). In a trial in Marlborough, above ground biomass of bracken fern without grazing peaked in year 7 at 7,100 g/m², where below ground biomass peaked in year 17 at 12,500 g/m² (Bray, 1991).

Bracken fern is considered an essential component of landscapes conserved for their historical significance to Māori. Māori relied on bracken rhizome starch as a major element of their diet. The burning of native forest by early Māori in the Tutira catchment (Hawke's Bay region), resulted in higher rates of sedimentation (McGlone et al., 2005). Bracken fern was then the primary coloniser of this landscape, showing to be nearly as effective as native forest at preventing erosion. The subsequent conversion of this catchment from bracken fern dominant to pasture species resulted in sedimentation rates increasing by a factor of five (McGlone et al., 2005).

4.4 TECHNIQUES NOT IMMEDIATELY APPLICABLE TO NZ NATIVE SPECIES

The techniques explained in this section are included in this review due to their relevance and importance as bioengineering techniques, even though they are not immediately applicable to New Zealand native species. These could become available in the medium to long term, depending upon the investment in and results of research trials. The ability for species to grow from cuttings when inserted into the ground as a bioengineering technique has dual benefits (USDA, 1992). The primary benefit that this provides is the physical support the stake provides, either pinning material to a slope or the tension it provides connecting different soil layers. The secondary benefit occurs when a tree or shrub grows from a stake, providing additional tension and anchoring the roots to the slope. Vegetation also removes excess water from a slope through transpiration, improving the overall erosion control effectiveness of this mitigation (USDA, 1992).

The majority of native woody plant species in New Zealand are raised from seed, with a small number of species raised from cuttings or divisions (Bergin, 2012). However, given the growing interest in using native species for erosion control, the use of cuttings as a technique may require further research for a wider range of native species, including the potential for plant breeding to bring about the ability of our native species to perform this function. This recommendation may be essential to achieve the multiple benefits of erosion control, such as improved water quality and biodiversity outcomes, in situations where bioengineering techniques are required above generic planting.

4.4.1 Live staking

Live staking is a technique involving the cutting of vegetative branches off trees that are approximately 1.3-3.8 cm in diameter and 60-90 cm long (USDA, 1992). The woody plants are used as reinforcement to reduce soil movement and therefore erosion processes. One end of the cutting should be sharpened and the other end should be square to allow the cutting to be hammered into the erodible ground. On its own, live staking lacks any immediate direct effects on erosion control. Effectiveness begins as stakes begin rooting. When these vegetative cuttings are placed in the ground, roots develop and foliage sprouts, eventually resulting in vegetation binding to the soil. Then this vegetation intercepts raindrops, maintains infiltration, filters runoff and prevents erosion processes from occurring in the landscape. The two common tree species for live staking are willows and poplars. Live staking is suitable on small earth slips and slumps where soil moisture is not limited. This technique is most successful where the stakes are planted in the wettest zones on banks where it is often wet.

Cross section
Not to scale

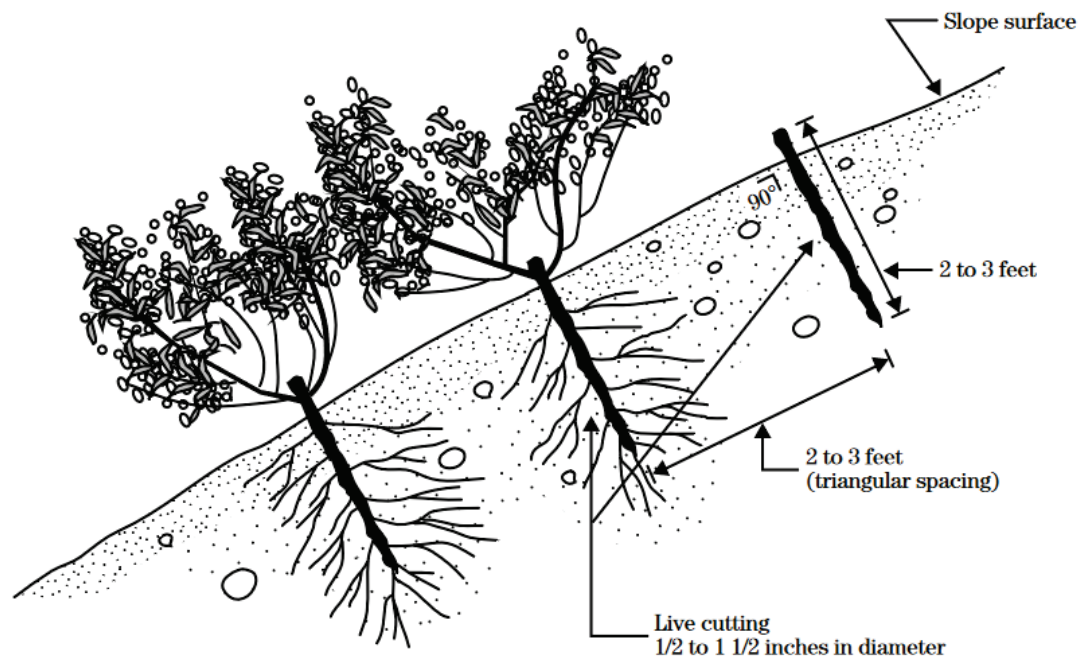


Figure 3: Cross section of live staking bioengineering technique (Meadows et al., 2002)

Live staking is a simple and inexpensive tool, commonly used for planting poplars and willows in New Zealand, that can be used on its own or used in conjunction with several other bioengineering techniques. It can also be used as a living peg to hold down other bioengineering materials such as geotextile coverings or used as a stabiliser for live fascines (USDA, 1992) (Figure 3).

4.4.2 Live fascine

Live fascines are long bundles of tree branches bound together with twine in bundles that are 2 to 3 long and 15 to 20cm in diameter (USDA, 1992). The cuttings should be staggered so that ends of branches are evenly distributed, allowing for a continuous structure with uniform size. The bundles are then placed horizontally in trenches that are 30-45 cm wide and 15-20 cm deep. The trenches are filled with moist soil leaving the top of the fascine visible above the soil. This process is then repeated at intervals along contour to create ‘terraces’ on dry slopes or at angles on wet slopes to facilitate drainage from the trenches (Figure 4). The trenches immediately trap and hold soil, while the terraces formed help slow the movement and erosive energy of the water running down the slope, helping to reduce sediment losses (USDA, 1992).

LIVE FASCINE

(Not to scale)

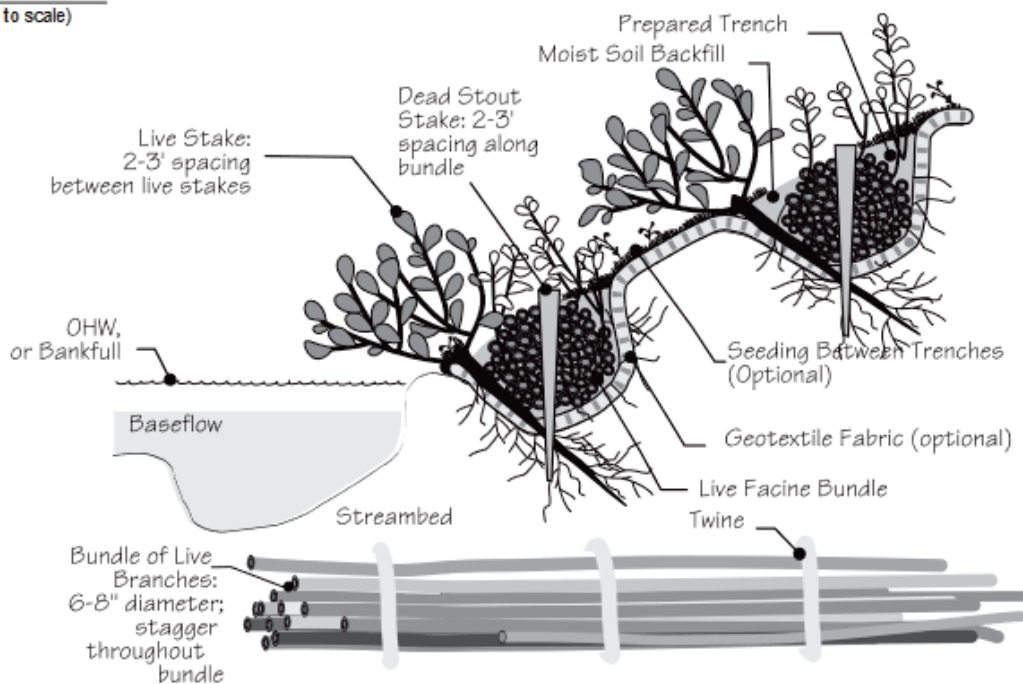


Figure 4: Cross section of live fascine bioengineering technique (Meadows et al., 2002)

Construction of live fascines is a labour-intensive process; however, it requires no heavy machinery, which makes it a good option in remote, or inaccessible sites where major earthmoving is not necessary. The establishment of live fascines does not disturb the surrounding environment and the trenches offer immediate reductions in surface erosion with the branches rooting and stabilising slopes over time. Once vegetated the live fascine creates a microclimate that facilitates further vegetative establishment.

Live staking and live fascine are used in combination with each other. Live stakes are used on the down slope side of the trenches to prop up the live fascine where required along the slope. Where there is overlapping bundles, more live stakes can be used (USDA, 1992).

4.4.3 Brush layering

Brush layering is a bioengineering technique where dormant woody cuttings from shrubs or small trees are laid in shallow trenches at various angles creating an interlaced layer (Salter et al., 2020). The portion of the brush that protrudes from the slope face assists in slowing runoff and reducing surface erosion. Brush layering is similar to live fascines in that cuttings are planted densely and horizontally along the contour instead of vertically. However, rather than using 2-3 m length cuttings, laying lengthwise parallel to the contour, cuttings are typically less than a metre and are driven perpendicular into the contour of the land. Brush layering produces plants with a deeper rooting system, compared to live fascines which are typically shallower in rooting depth.

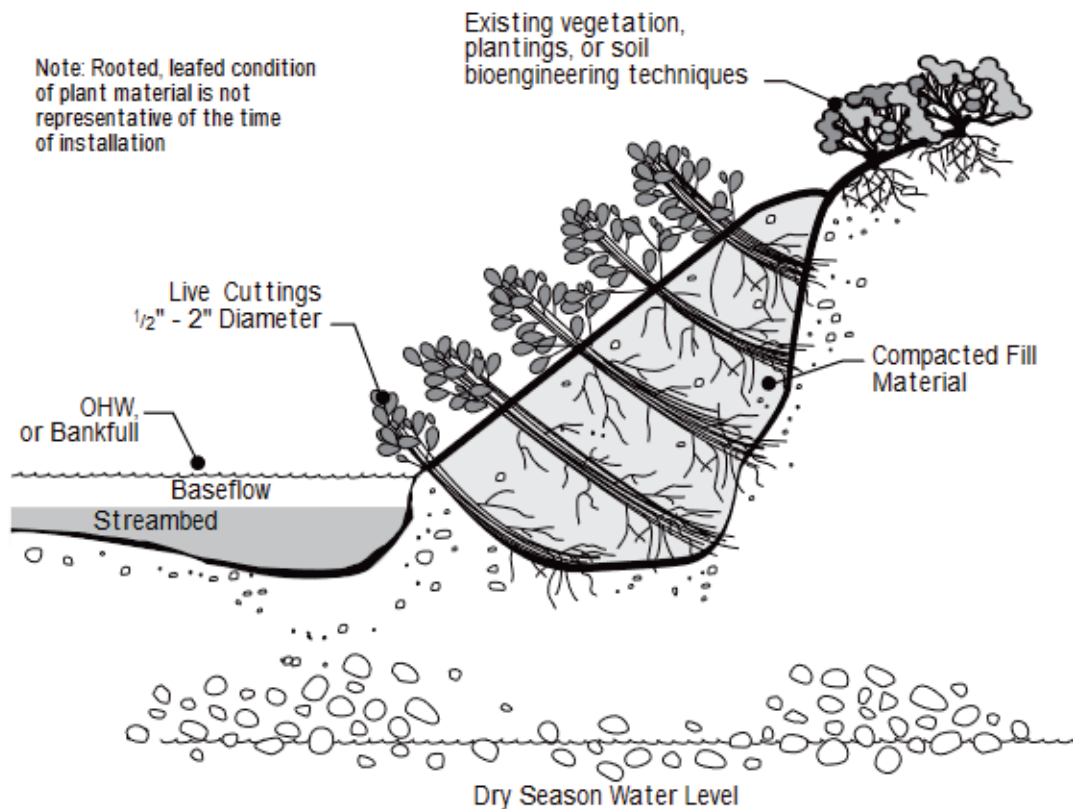


Figure 5: Cross section of brush layering bioengineering technique (Meadows et al., 2002).

Branches are placed on an angle that follows the contour of the slope and provides reinforcement to the soil. Physical branches trap debris on the slope and reinforce the soil. When roots develop this adds significant resistance to the slope, reducing soil displacement. When the slope is fully vegetated it promotes natural germination and regeneration, aiding infiltration of dry sites. The woody barrier is an instant physical barrier that immediately interrupts runoff. Brush layering allows for the slope to be broken up into smaller sections, reducing the erosive energy on the slope as well as improving the infiltration (Figure 5).

Brush layering is often successful on stony debris or can be used with shade tolerant tree species, where this bioengineering technique can be used under existing tree canopies. It is limited to shorter slopes no greater than 4 m in height and no steeper than 45° gradient (USDA, 1992).

4.4.4 Branch packing

Branch packing is the process of laying alternate layers of vegetative cuttings with compacted back fill between them. Branch packing is used to repair small, localised slumps and holes in streambanks less than 60-120 cm wide and 120 cm deep. Branches should be 1.2-2.5 cm in diameter with supporting live stakes (1.5-2.5 m long) hammered through to undisturbed ground underneath. Stakes are driven vertically 90-120cm into the ground about 30-40 cm apart (USDA, 1992).

BRANCH PACKING (Not to scale)

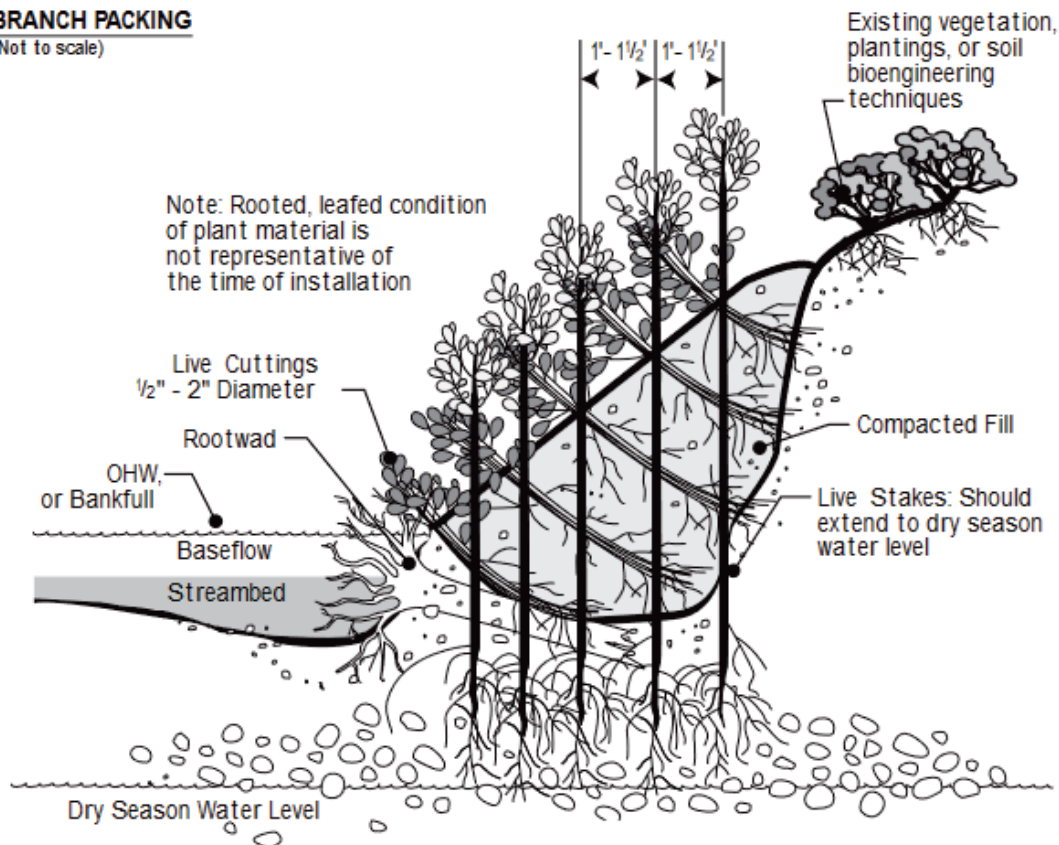


Figure 6: Cross section of branch packing bioengineering technique (Meadows et al., 2002).

Layers of live branches are laid in a crisscross manner in the slump facing out of the slope. A layer of soil is applied between each layer as thick as the branches and compact fill. The final layer should be finished so that the infill of soil matched the preexisting slope face before the slump/hole (Figure 6).

Branch packing almost immediately reinforces the soil and therefore reducing runoff and surface erosion. This practice provides immediate soil reinforcement, serving as tensile reinforcement once live branches are installed. It establishes a vegetated stream bank rapidly, retarding runoff and surface erosion and cuttings become vegetative. It also enhances the conditions of the surrounding area for colonisation of native vegetative species (USDA, 1992).

4.4.5 Trench packing

Trench packing is placing branch cuttings, typically from deciduous trees due to their good rooting structure, vertically in trenches or holes along the higher water mark of stream banks (Figure 7). Trench packs can be used perpendicular across flood plains or along stream banks. Plant cuttings should be selected from the same zones in which they will be planted e.g. streams edge, bank or floodplain (USDA, 1992).

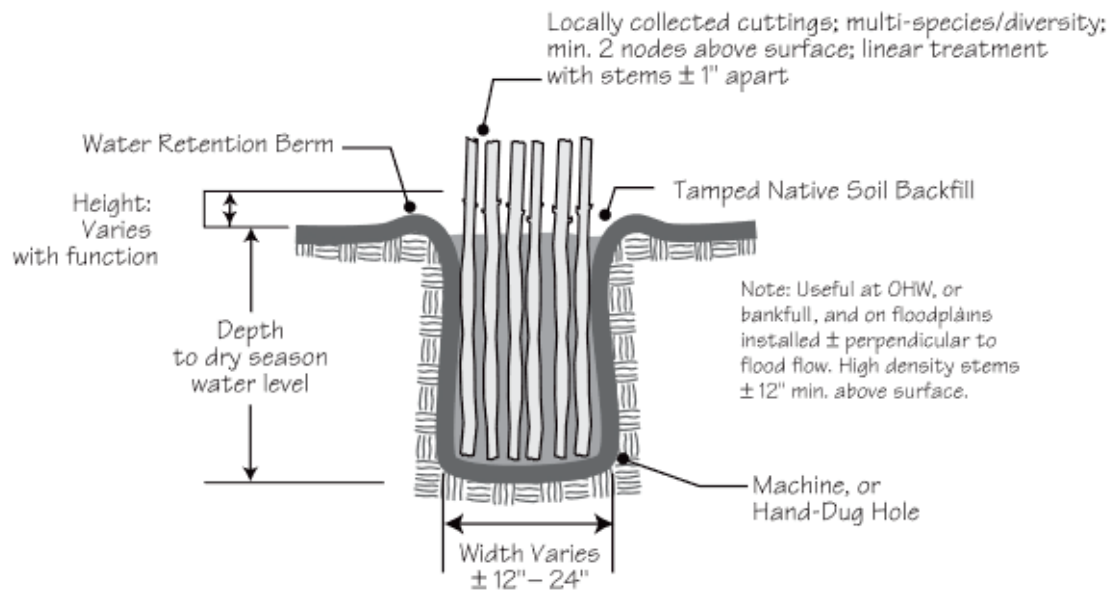


Figure 7: Cross section of trench packing bioengineering technique (Meadows et al., 2002).

Trench packing slows and reduces the erosive energy of moving water and wind, trapping sediment in the process. Using trench packing for erosion control can be beneficial for bank stabilisation and by reducing wind and water velocity, capturing soil around the cuttings, reinforcing the banks stability. This technique can dry wet areas through evapotranspiration and facilitates the colonisation of nearby vegetation communities through microclimate effects conducive to plant growth (USDA, 1992).

5 Knowledge gaps and recommendations

This review of native forest establishment projects on erodible land and techniques that are used within New Zealand and internationally has highlighted several knowledge gaps. To address these, we recommend research or techniques that could be explored further for the New Zealand context. These are listed as follows and summarised along with recommendations in Table 2.

Table 2: Knowledge gaps identified and recommendations

Knowledge gap	Notes and recommendations
Post planting recording/monitoring	Many native forest establishment projects on highly erodible lands state their methods and plans for establishment. However, very few monitor or quantify their successes and failures. We recommend that funding for native planting prioritises post establishment monitoring and making information and lessons publicly available.
Knowledge on and practical tools to select native plants for erosion control	We support the recommendations made by Phillips (2005) around exploring the best native plants for erosion control and other roles, how they function outside of their ecological niche and what combinations of species are possible given desired outcomes. Much of this information is available in reports and on websites, but could be made more accessible by incorporating it into decision support tools. MPI TUR could explore and test existing tools for native afforestation purposes, including e.g. native plant selection tools and calculators.
The potential of ferns and mosses for erosion control	We recommend further exploration of hardy ferns such as bracken fern (<i>Pteridium esculentum</i>) for their potential use as a pioneer species that creates a suitable environment for regenerating forests while providing some initial erosion control mitigation. Kiokio (<i>Blechnum novaezealandiae</i>) is another fern species worth investigating.
Space planting of native species	Space planting in New Zealand commonly uses exotic species such as poplar and willows, although Manuka is also used. Further research is needed to determine the role of different native species in space planting approaches.
The potential for native plant species to be used for live staking, live fascine, brush layer, branch packing and trench pack techniques	Propagating native species from cuttings requires further research, including plant breeding into the ability of our native species to perform this function. This may open up further establishment possibilities where generic planting is not feasible, such as live staking, live fascine, brush layer, branch packing and trench pack techniques.
Non-native shrubs for nurse crops on eroded land	We recommend that areas already colonised with non-natives shrubs (e.g. gorse, broom) could be explored for their suitability and effectiveness as nurse crops for native forest. Rather than paying to remove them, these exotic pioneers could be strategically removed or succeeded by native species.
The applicability of different approaches to establishing seed islands	Two projects reviewed are trialling seed islands to assist with the natural regeneration of native forest. The Whakatipu Beech seeding project (Paul et al., 2020) is trialling the direct application of seed to these “islands” and the Waikereru Ecosanctuary project is manually planting seed island areas. We recommend that these trial projects are followed as they progress, in order to understand where these different approaches to establishing seed islands are most successful. Further research may be required to test these approaches on highly erodible land in other circumstances or regions not covered within the trials.
Drone seeding	Drone seeding trials on inaccessible slip faces are underway for the Waingake Transformation Programme. We recommend that these trials are followed to determine if this is a feasible approach for highly erodible land and could be used for other projects.

Economics of timber and non-timber products

While not the focus of this review, we recognise that afforestation on highly erodible land will require resources, hence we recommend exploring potential income streams from both timber and non-timber products in eroded land.

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Appendix A – Native forest establishment projects on highly erodible land

Project description	Erosion control challenges and success factors	References
<p>Waingake transformation programme</p> <p><i>Te Tairāwhiti (Gisborne region)</i></p> <p>A partnership between Gisborne District Council and mana whenua Maraetaha Incorporated supported by Ngai Tāmanuhiri to transition 1,200 ha of pine plantation to native forest, which includes areas of steep, erodible land.</p> <p>Started approximately 2018; ongoing.</p>	<p>A key strategy is to establish vegetation cover to help stabilise the land, with highly erodible and engineered land prioritised for planting.</p> <p>Restoration work was impacted by Cyclone Gabrielle and Cyclone Hale in early 2023, resulting in a lower target for planting than initially planned and efforts directed towards assessing impacts on the project area.</p> <p>Plant losses were experienced in some areas due to slips as a result of the cyclones and other severe weather events in 2023. Due to health and safety risks, slip areas are not planned for manual replanting.</p> <p>The project is trialling drone seeding onto slip faces, which could be a safe and cost-effective method for regenerating native vegetation on these areas that are inaccessible for manual planting.</p>	<p>(England, 2023)</p> <p>(White & Foreman, 2020)</p>
<p>Lake Tutira mānuka plantation</p> <p><i>Lake Tutira, Hawke's Bay region</i></p> <p>A Primary Growth Partnership – Mānuka Research Partnership Ltd (MRPL) project establishing a trial planting of 130ha of mānuka on steep erosion prone land adjacent to Lake Tutira. The wider project had an aim of growing the mānuka honey industry, with the additional benefits of preventing erosion and in the longer term establishing native forest on the</p>	<p>Plantings of low-density mānuka were established on moderately steep to steep slopes classified as erosion prone LUC 6e and 7e land.</p> <p>The Tīmata method was used, planting smaller forestry grade mānuka seedlings in parallel lines at lower densities (3 x 3m; 1111 stems per hectare). Permanent sample plots were established in 2015 to monitor growth characteristics.</p> <p>Tree establishment was poorer on steeper rock seams where topsoil was minimal or absent.</p>	<p>(Dewes et al., 2022)</p> <p>(Marden et al., 2020)</p>

Project description	Erosion control challenges and success factors	References
<p>land. The MRPL has since formed Mānuka Farming NZ and advises landowners on establishing mānuka plantations for honey production.</p> <p>2011-2018</p>	<p>Canopy closure and natural regeneration has been observed for the planting, with secondary native species growing through the mānuka.</p> <p>It was concluded that mānuka plantings using this approach would take 6.5-9 years to reach canopy closure and root occupancy. Kānuka planted at higher stocking rates (2 x 2m; 2,500 stems per hectare) was recommended for the site if the primary goal was native forest establishment.</p>	
<p>Mahurangi East Land Restoration Project</p> <p><i>Warkworth, Northland region</i></p> <p>This project is jointly led by Ngāti Manuhiri Settlement Trust and Auckland Council, with an aim to reduce sediment entering the Mahurangi River catchment. Although many parts of the project are focused on riparian restoration, the catchment scale of the project also includes supporting native forest planting on steep farmland and forestry blocks for slope stabilisation.</p> <p>Started in 2004; ongoing</p>	<ul style="list-style-type: none"> • An erosion and sediment control plan has been developed for the catchment. • The West Mahurangi sub-catchment was identified as high risk due to steep land with high areas of exposed soils and slips and is one of the highest contributors of sediment into the Upper Mahurangi Harbour. • Riparian control measures for sediment reduction are a key focus. • Recommended options for erosion control on steep land include agroforestry and forestry establishment where trees can be safely planted and harvested, and retaining scrub and natural reversion practices where land is too steep for planted forest. These approaches are recommended to be captured within land management plans. 	<p>(Temple & Parsonson, 2014)</p>

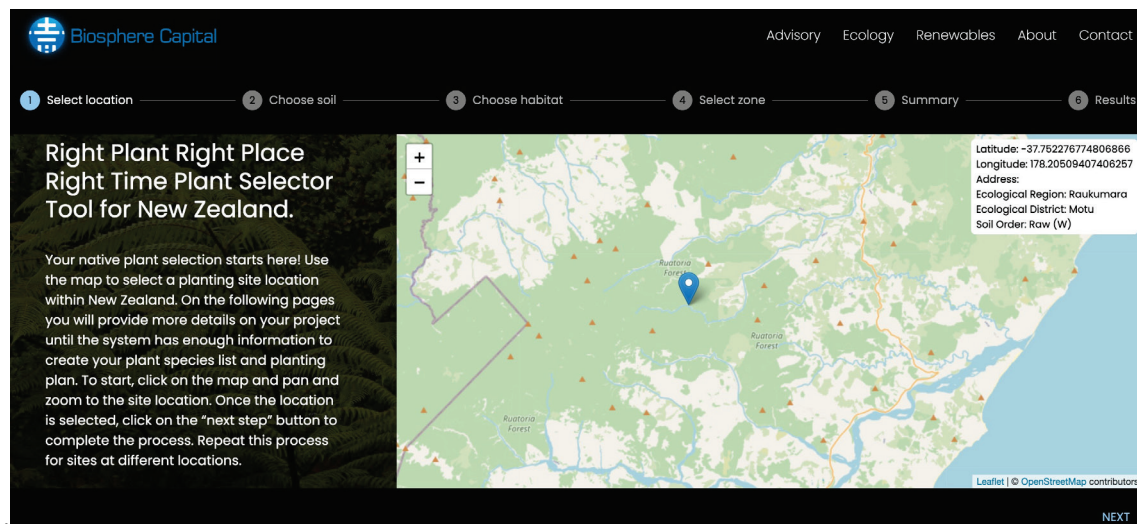
Project description	Erosion control challenges and success factors	References
<p>Waikereru Ecosanctuary Seed Island Project</p> <p><i>Te Tairāwhiti (Gisborne region)</i></p> <p>The Waikereru Ecosanctuary is an area of over 100ha of marginal hill country in Tairāwhiti, a significant portion of which is regenerating to native forest. Tāne's Tree Trust is working alongside the Longbush Ecological Trust to demonstrate a trial area of native tree seed islands within the ecosanctuary.</p> <p>Unknown start dates and unknown if ongoing</p>	<p>Seed islands are being trialled – these are small areas of intensive native plantings which will over time start to produce seed and support the native forest regeneration of adjacent areas, as seed is spread from these areas.</p> <p>The trials are also incorporating a network of plots to monitor how the regeneration is progressing.</p>	<p>(Tāne's Tree Trust, 2023a)</p> <p>(Trees that Count, 2023)</p> <p>(Trees That Count, 2023)</p>
<p>Perkins Farm Escarpment Revegetation</p> <p><i>Paekākāriki, Kapiti District</i></p> <p>The Ngā Uruora – Kāpiti Project Inc. is a registered charity organisation with an aim to restore the coastal forested areas of the Kāpiti – Porirua coast. The Perkins Farm escarpment is an area of retired steep and exposed farmland that is adjacent to the main focus area of the Ngā Uruora restoration work.</p> <p>Started 2013, unknown if ongoing but mentioned in the Ngā Uruora animal pest control operational plan 2018-2021</p>	<p>The Waikakariki and Hairpin Gullies within the Perkins Farm escarpment consist of mostly class 8e and 7e erosion-prone land which are susceptible when there are large storm or earthquake events.</p> <p>There is also a focus on revegetating steep slope areas above Transmission Gully to mitigate construction work.</p> <p>A large flooding event in 2003 caused significant landslides, gully erosion and debris flood deposits. Forested areas had less erosion than less vegetated areas.</p> <p>The project has suggested building gates across the valleys to stop movement of loose material during large flood events. Vertical rails and tyres used within the Hairpin Gully were shown to be partly effective. The report suggests that “engineers should investigate the feasibility, costs and benefits of gates built at intervals across the valley floor, preferably just downstream of actively eroding side gullies”</p> <p>It was observed that the understorey of the Hairpin Gully forested area “quickly rebounded” after being fenced off</p>	<p>(Ngā Uruora Committee, 2013)</p> <p>(Ngā Uruora – Kāpiti Project (Inc), 2018)</p>

Project description	Erosion control challenges and success factors	References
	<p>from grazing sheep. Forest has also been observed to be naturally regenerating along forest margins.</p> <p>A mixture of natural revegetation and planting is being used as part of restoration plan.</p> <p>Native species observed to be regenerating naturally and acting as nurse crops included tauhinu and pohuehue.</p>	
<p>Ngā Kaitiaki o Te Awa o Pūniu</p> <p><i>Pūniu River, Waikato region</i></p> <p>Pūniu River Care Inc. led this five year project to protect and restore the mauri of the Pūniu River, with a focus on erosion protection works and planting native trees.</p> <p>2018-2023</p>	<p>Considerable erosion is occurring along the banks of the Pūniu River, with over 10,000 tonnes of sediment entering the adjoining Waipā River annually.</p> <p>The project has focused on fencing to exclude stock, planting natives, and other erosion protection works to protect the riverbank from eroding further.</p> <p>Another project aim was to generate a marae-based restoration guide to support other organisations carrying out similar protection work.</p> <p>Proposed restoration measurements include mahinga kai species and tuna stock monitoring as a physical measure of river health and reduced sedimentation.</p>	<p>(Pūniu River Care, 2021)</p>

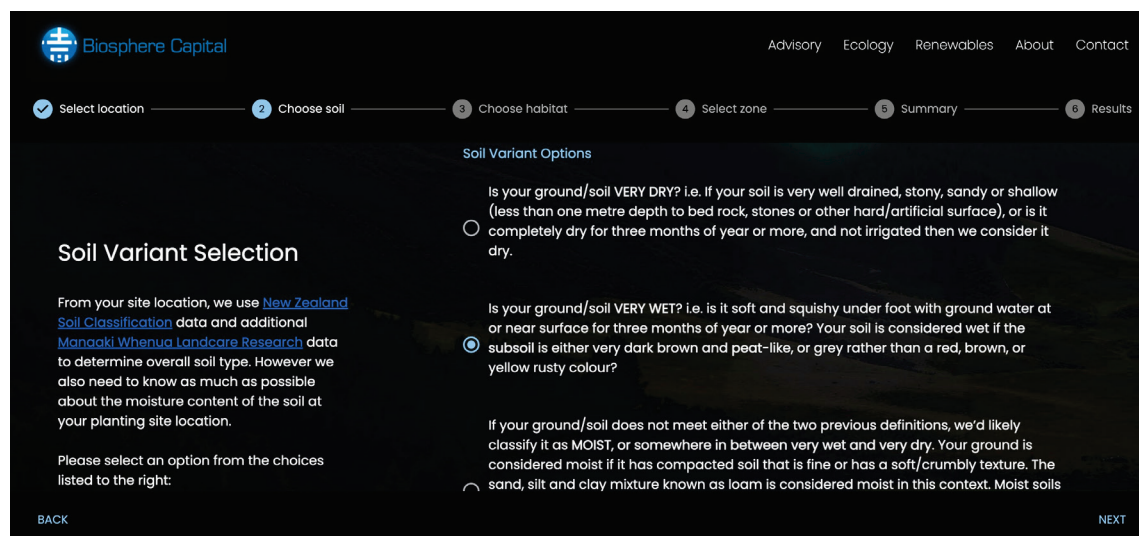
Appendix B – Native plant species selector tool (Beta version)

This Native plant species selector tool has been made available to the authors of this report for testing. Permission was obtained from the creator, ecologist Dr. Colin Meurk ONZM, to present this appendix including screenshots and a blurb of the tool.

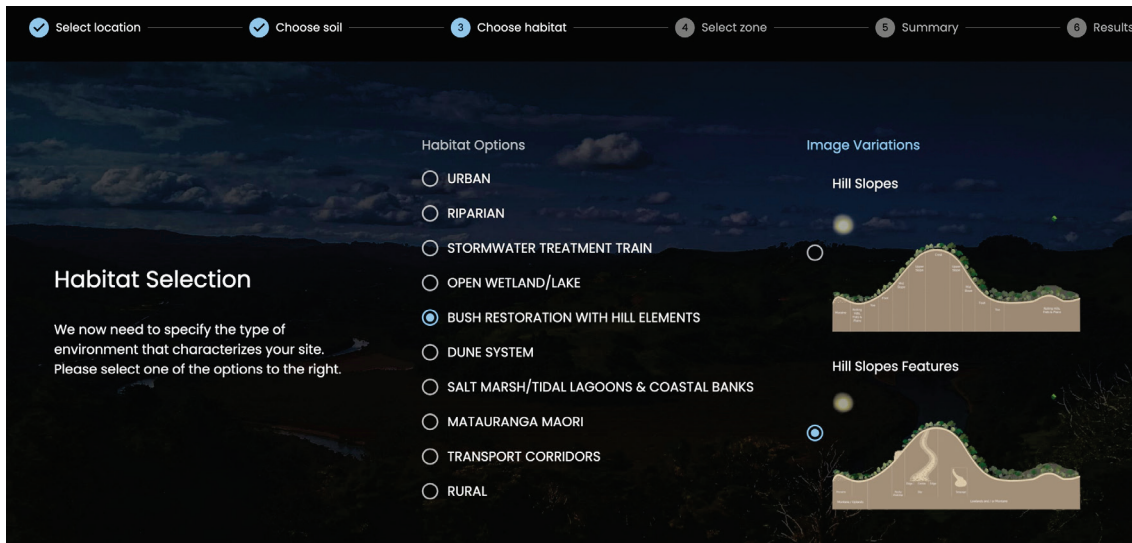
The predecessor of this tool was formulated at Manaaki Whenua Landcare Research but subsequently developed independently with funding support from Envirolink and some councils including Environment Canterbury, Selwyn District and Waimakariri District. The tool consists of six steps that allow the user to select the location to be planted, soil moisture, and broad habitat/context (urban to rural restoration/landscaping), then specific planting elements or zones, including erodible land. It produces a list of suitable plants for afforestation, restoration or landscaping, their characteristics and tolerances, and the planting stage/sequence. Hence the tentative name of the tool – “Right Plant-Right Place-Right Time”.



Step 1. Location to be planted. The user can zoom to a point on a map. Data on geographical coordinates and ecological region, district and soil order are generated.



Step 2. The user then chooses the soil moisture conditions: from very dry, very wet or moist.



Step 3. Broad Habitat/Context selection. The choices range from urban to rural landscapes. Of particular interest to this review report is the “Bush restoration with hill elements”



Step 4. Zone selection. The choices of hill slope features include: moraine, rocky outcrop, slip (edge or centre) and seepage.

Please review your choices presented below:

1. Location Data ^

Geographical Coordinates (latitude, longitude) (-37.752276774806866, 178.20509407406257)

Ecological Region

Raukumara

Ecological District

Motu

Property Name

2. Soil Properties v

3. Project Site Details v

Step 5. The tool confirms the parameters chosen so far, location, soil properties and project site details.

Plant List Results DOWNLOAD PDF DOWNLOAD CSV

Please review the plant species list. It can be saved as a CSV file or appended to a planting plan guidebook. Additional information on each species can be obtained by entering the plant species name into the search box at naturalist.nz or in the "search flora" box at www.nzpcn.org.nz. Click the "Download PDF" button to create a planting plan guidebook specific to your project site.

Names	Growth Form / Max Height (m) / Spacing (m) / Forest Position	Moisture Preferences	Tolerances (Water / Drought / Frost / Salinity)	Ecosystem Services	Carbon Sequestration Rate	Planting Stage
<i>Aristotelia serrata</i> / wineberry; makomako	Small Tree / 8 / 15 / B, C	Mesic	L / M / M / L	Erosion control, Nectar (Insect), Fruit (Bird)		1
<i>Carex coriacea</i> / cutty grass; rautahi / <i>Carex geminata</i>	Tall Turf / 0.6 / 0.5 / B	Wet, Mesic	H / H / H / L	Erosion control, Filtration, Grain (Bird)		1
<i>Carex geminata</i> / cutty grass; rautahi / <i>Carex coriacea</i>	Tall Turf / 0.8 / 0.75 / B	Wet, Mesic	H / H / H / L	Erosion control, Filtration, Grain (Bird)		1
<i>Carex virgata</i> / pukio	Tall Tussock / 1 / 1.0 / B	Wet, Mesic	H / M / H / M	Erosion control, Filtration, Grain (Bird)		1
<i>Chionochloa conspicua</i> / bush tussock; broad-leaved bush tussock	Tall Tussock / 1.4 / 1.5 / S	Mesic	M / M / H / M	Erosion control, Grain (Bird)		1
<i>Cordylina australis</i> / cabbage tree; ti kouka; ti	Medium Tree / 15 / 3.0 / B	Wet, Mesic, Dry	H / H / H / M	Erosion control, Filtration, Fibre, Food, Shelter, Shade, Nectar/Pollen (Lizard), Nectar (Insect), Fruit (Bird), Fruit (Lizard), Cultural		1
<i>Cortaderia fulvida</i> / toetoe; kokaho / <i>Austroderia</i>	Tall Tussock / 1.5 / 1.5 / S	Wet, Mesic	M / M / H / M	Erosion control, Filtration, Fibre, Shelter, Coastal Shelter, Grain (Bird), Cultural		1
<i>Cortaderia toetoe</i> / toetoe / <i>Austroderia</i>	Tall Tussock / 1.5 / 1.5 / S	Wet, Mesic	M / M / H / M	Erosion control, Filtration, Fibre, Shelter, Coastal Shelter, Grain (Bird), Cultural		1
<i>Leptospermum scoparium</i> / manuka; red tea tree	Small Tree / 8 / 1.5 / B	Wet, Mesic	H / H / H / L	Erosion control, Filtration, Timber, Fibre, Food, Shelter, Coastal Shelter, Shade, Nectar (Bird), Nectar/Pollen (Lizard), Nectar (Insect), Fruit (Bird), Fruit (Lizard), Cultural		1
<i>Myrsine divaricata</i> / weeping mapou; weeping matipo	Tall Shrub / 5 / 1.5 / B, S	Wet, Mesic, Dry	H / M / H / L	Erosion control, Shelter, Nectar (Insect), Fruit (Bird), Fruit (Lizard), Cultural		1
<i>Phormium tenax</i> / New Zealand flax; harakeke; flax	Tall Tussock / 2.5 / 1.5 / B	Wet, Mesic	H / M / H / M	Erosion control, Filtration, Fibre, Shelter, Coastal Shelter, Nectar (Bird), Cultural		1
<i>Carlia arborea</i> / tree tutu	Small Tree / 8 / 1.5 / B	Mesic	M / L / M / L	Erosion control, Nectar/Pollen (Lizard), Nectar (Insect), Fruit (Bird), Fruit (Lizard)		2
<i>Myrsine australis</i> / mapou; red matipo	Small Tree / 7 / 1.5 / B, C	Mesic	M / M / L / M	Erosion control, Shelter, Coastal Shelter, Shade, Nectar (Insect), Fruit (Bird), Fruit (Lizard)		2

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Step 6. The final output is a comprehensive list of species, growth characteristics, moisture preference, tolerances to water, drought, frost and salinity (Low to High), ecosystem services and importantly, the planting stage.